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THE PROPERTIES AND USES OF HELIUM

(INCLUDING A COMPREHENSIVE BIBLIOGRAPHY, 1933-45)

BY

HENRY P. WHEELER, JR.

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

THE PROPERTIES AND USES OF HELIUM[1]

(Including a Comprehensive Bibliography, 1933-45)

By Henry P. Wheeler, Jr.[2]

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2/ Petroleum engineer, Bureau of Mines, Washington, D. C.

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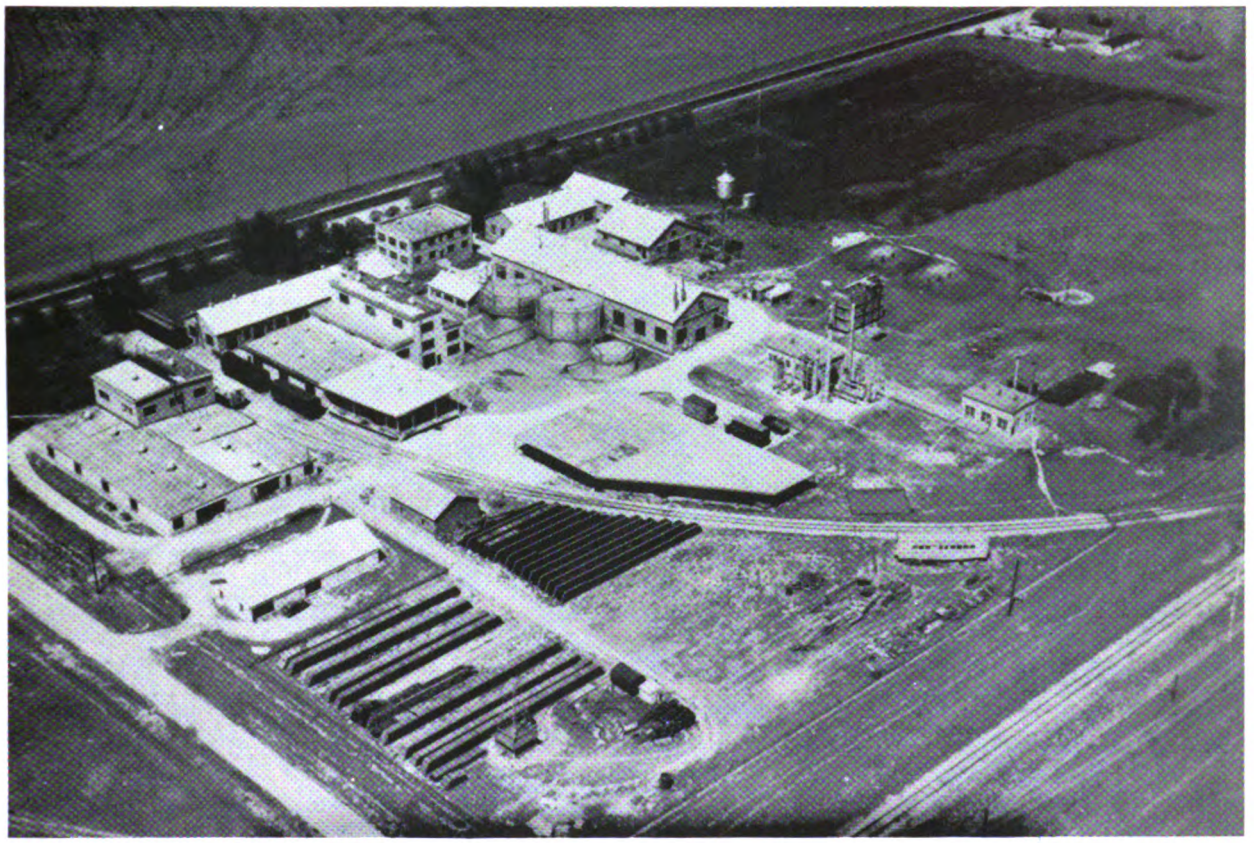

Figure 1. - Bureau of Mines helium plant, Amarillo, Tex.

Figure 2. - Helium-filled blimp in flight (official photograph, U. S. Navy).

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INTRODUCTION

As recently as 1915, helium was available only in very small quantities at a cost equivalent to $2,500 per cubic foot. It was a laboratory curiosity, and its properties were of interest to a limited number of scientists (11).3/

During the past 30 years, however, helium has grown from a plaything of scientists to a factor of importance in the prosecution of the recent war. Navy blimps filled with nonflammable helium proved to be more than a match for German submarines operating in the Atlantic. American bombers were able to fly unheard-of distances to drop bombs on Tokyo, Nagoya, Yokahama, and other Japanese cities because they had been made lighter with magnesium, arc-welded in a helium atmosphere. The Army utilized helium-filled radio-sonde balloons to obtain vital information concerning weather conditions affecting D-day invasions and other military maneuvers.

What can helium do after the war? It is now available in large enough quantities to assure private enterprise a continuous supply. If equipment involving the use of helium is designed by a manufacturer, that manufacturer must know that he can get helium. He is able to buy it now for approximately 1 cent per cubic foot as long as he needs it. Before the war, manufacturers tended to shy away from helium, for they knew that the Government was the sole producer and their needs would be met only after the Army and Navy received their requirements. This is still true, but the helium-production capacity of the Bureau of Mines has been increased to such an extent that the requirements of Army, Navy, and private enterprise can be met easily and simultaneously. As much as 10,000,000 cubic feet per month is available for private enterprise alone. (see fig. 1).

Thus, a new tool is available to American industry - a tool that bears a "made in America" brand, for only in the United States is helium produced.

ACKNOWLEDGMENTS

The author desires to express appreciation to R. A. Cattell, H. S. Kennedy, and C. W. Siebel of the Bureau of Mines, who contributed many

3/ Numbers in parentheses, unless otherwise obviously significant, refer to the list of references in part A of the Bibliography at the end of this paper.

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valuable suggestions and much constructive criticism in the preparation of this paper.

EXTREME PROPERTIES[4]

The most notable thing about helium is its wide range of properties. The things helium will do, it will do well - better than most gases always and better than any other gas in some applications. The things that helium will not do well, it will at least do to a very limited extent, and some things it will not do at all.

WHAT HELIUM WILL DO

Helium is monatomic: its molecule is the simplest of any element. The molecular weight of helium is 4.003; its density is 0.1785 grams per liter at 0° C. and 760 mm. mercury pressure - 10.54 pounds per 1,000 cubic feet at 60° F. This gives it a lifting power in air of 65.82 pounds per 1,000 cubic feet, second only to hydrogen and 92.64 percent as great. The average velocity of a helium molecule at 0° C. has been calculated and found to be 1,208 centimeters per second, faster than the molecule of any other gas except hydrogen.

Diffusion and Rate of Permeability

As helium is the second-lightest gas, its rate of diffusion is greater than that of any other gas except hydrogen. Graham's law states that the relative rates of diffusion of gases under the same conditions of temperature and pressure are inversely proportional to the square roots of their densities.

The rate at which the lifting gas escapes from lighter-than-air craft is of great concern to designers and operators of such craft. Experiments have shown that the process by which gas penetrates balloon fabric is not diffusion alone. Some gases are lost more rapidly than Graham's postulates. Carbon dioxide, for example, is much heavier than hydrogen or helium, but it escapes from balloon fabric much faster. This phenomenon has been explained by scientists who believe that the process is one of solution and evaporation. Gas is dissolved by rubber and is evaporated on the opposite surface. This explanation is feasible because it has been shown that permeability of rubber to gases is proportional to the partial pressure of the gas and the thickness of the rubber (3).

At the same temperature, helium penetrates rubber vulcanized on balloon fabric 85 percent as fast as hydrogen, approximately three times faster than air, and one-fourth as fast as carbon dioxide. The rate at which a gas penetrates rubber is defined as the permeability of rubber to that particular gas. Usually the rates are expressed relative to hydrogen and referred to as "relative permeability."

4/ Tables at end of paper show properties of helium and some other gases.

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At high temperatures helium diffuses through cellophane, quartz, and porcelain but will not diffuse through platinum, palladium, or iron. Some theorists believe that helium creeps through minute cracks between quartz crystals because it will not diffuse through a single crystal (12).

Thermal Properties

Helium conducts heat better than any other gas except hydrogen. Its specific heat or heat capacity is approximately five and one fourth times that of air, when expressed on a weight basis; on a volumetric basis, the specific heat of helium is slightly less than that of air. Unlike other gases at normal temperatures, helium, hydrogen, and neon become warm when allowed to expand into a region of low pressure without accomplishing external work. It is said, therefore, that these gases have a reverse Joule-Thomson effect at normal temperatures. At low temperatures these gases have a normal Joule-Thomson effect and can be liquefied by expansion after being cooled below the inversion temperature. Estimates of this temperature range from 173° below 0° C. at atmospheric pressure (7), to 233° below 0° C. at pressures up to 60 atmospheres.

Electrical Properties

Helium conducts an electrical current better than any other gas except neon. Its minimum spark potential is 184 volts at 2.4 mm. mercury pressure. Under the same conditions of potential and pressure, a spark can be obtained in helium approximately seven times as long as in air or hydrogen and five times as long as in argon. The rate of ionization of helium when bombarded with electrons is slower than for any other gas, but the mobility of its ions is second only to hydrogen.

Sound waves travel faster in helium than in any other gas except hydrogen.

WHAT HELIUM WILL NOT DO

One of the most striking properties of helium is its complete inertness. It will not burn, explode, or combine with any other element; consequently, there are no helium compounds. Helium is colorless, odorless, and tasteless; identification is accomplished principally by spectroscopic means.

Solubility

Helium is not known to be readily soluble in any liquid. It is less soluble in water than is any other gas. Nitrogen impurity increases solubility appreciably (10).

Index of Refraction

A light wave is distorted less when it enters a helium atmosphere than when it enters any other gaseous atmosphere. The index of refraction of helium relative to a vacuum is very nearly unity.

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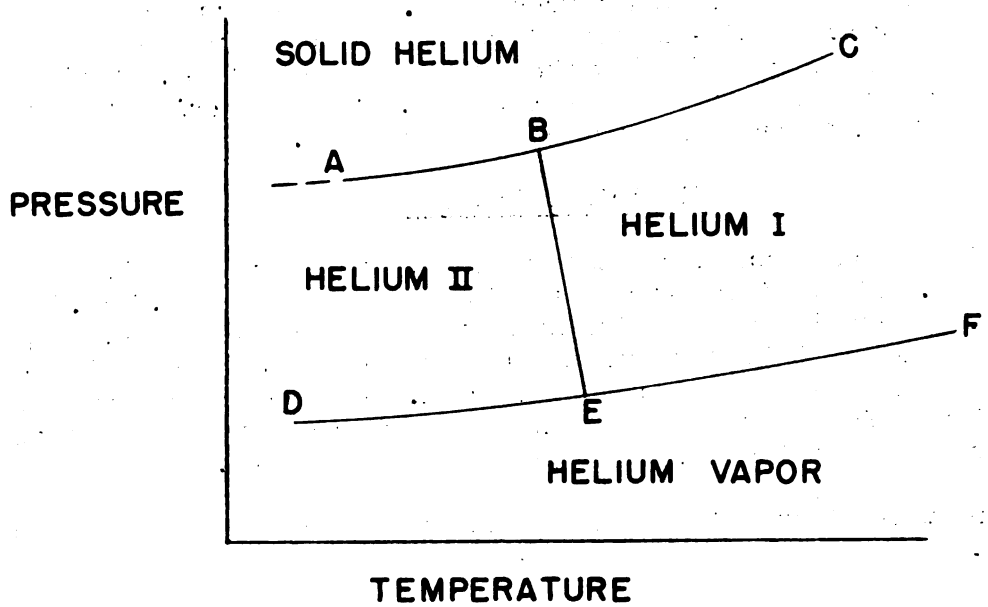
LIQUID HELIUM

Helium is the most difficult of all gases to liquefy. Its boiling point is 268.9° below 0° C., only 4.2° above absolute zero, the temperature at which, theoretically, all molecular motion should cease. Liquid helium is one of the most remarkable substances known. It exists in two distinct forms, known as helium-I and helium-II. The relationships among the two forms of liquid helium, solid helium, and gaseous helium are shown in the accompanying diagram taken from Thorpes Dictionary of Applied Science (12). The diagram is not drawn to scale.



Liquid helium exists as helium-I at normal pressures and can be kept for short periods of time in vacuum flasks. It is almost invisible but the surface can be detected by light reflected from it. Slow boiling produces a steady stream of bubbles rising through the liquid.

If the pressure is reduced to a point in the curve DE, transformation to helium-II occurs immediately. The only visible change is the sudden cessation of boiling. The point E is known as the lambda (λ) point, where helium-I, helium-II and helium vapor exists in equilibrium. This occurs at a temperature of 2.186° absolute and a vapour pressure of 3.83 centimeters of mercury. The line EB (the λ line) represents the variation of the λ-point with change of pressures. The specific heat of liquid helium is maximum at the λ-point, but no latent heat is associated with the change

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from helium-I to helium-II. The density at various pressures also is a maximum on the λ-line. Viscosity falls rapidly below the λ-point, and at 1.3° absolute temperature the viscosity of helium-II is only 1.24 micropoises (water has a viscosity of about 10,000 micropoises at 20° C). The thermal conductivity of liquid helium shows a remarkable change at the λ-point, changing from 6 X 10^{-5} gram-calories per square centimeter per second per degree centigrade at 3.3° absolute temperature (helium-I) to 190 (same units) at 1.4° - 1.75° absolute temperature (helium-II). Helium-II is by far the best conductor of heat yet discovered.

SOLID HELIUM

Helium has been solidified under 26 atmospheres pressure. Its melting point is 272.2° below 0° C. at that pressure. Because it is unstable at pressures less than 25 atmospheres, only a few of its properties have been investigated. The density of liquid helium is 0.23 gram per cubic centimeter at 4° absolute temperature; the heat of fusion is 6.75 gram-calories per gram.

HOW THE PROPERTIES OF HELIUM ARE USED

Lifting Gas

By far the greatest volume of helium is used in Navy blimps (see fig. 2). It is used because it will lift 92.64 percent as much load as hydrogen and will not burn. Helium diffuses from a balloon more slowly than hydrogen, and helium that has become contaminated with air can be purified cheaply and safely, whereas the purification of hydrogen presents many hazardous and expensive problems.

Developments and improvements in lighter-than-air craft as a result of the war have prompted resumption of studies and investigations with respect to the safety, efficiency, and economy of giant helium-filled dirigibles. The widespread publicity given by newspapers to the German Zeppelin disasters forced a temporary halt in these studies before the war. It is not generally recognized that the German dirigibles were filled with flamable hydrogen; postwar American dirigibles will be stronger, lighter, and filled with nonflammable helium. United States Navy blimps have engaged German submarines in surface battle; machine bullets and cannon fire have penetrated their balloon fabric. Some of them were shot down, but they did not burn; others returned to their base with holes in them. These facts emphatically express the reliability and safety of helium as a lifting gas.

Gas-Shielded Arc Welding

A new and growing use for helium is to provide an inert and at the same time excellent thermal and electrical conducting atmosphere for arc-welding light metals. Experiments have proved that helium is the best gas for this purpose. The gas-shielded arc-welding method was developed originally to be used in welding magnesium metal, which ignites in the presence of oxygen at welding temperatures. The method has been expanded

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to facilitate the welding of aluminum and stainless steel, normally without the use of flux. If a light-metal era occurs in the future, as many prominent industrialists predict, gas-shielded arc welding may prove to be the greatest post-war use for helium (see figs. 3 and 4).

Inert Atmosphere

Helium may be used to facilitate metallurgical processes by providing an atmosphere that will permit no oxidation or similar chemical action at any temperature. It is the only totally inert gas produced in large enough volume to be sold at a price low enough to permit its use in this manner. Its possibilities as a fire-fighting gas have not been investigated to a great extent.

Optical Instruments

When multiple optical lenses are arranged in series, helium may be used to fill the space between them. Light rays passing from a lens into helium gas are refracted less than in any other gas. The refraction of light by helium compares favorably with that of a vacuum which is difficult to maintain.

Breathing Atmospheres

Where it is necessary for divers, caisson workers, or other persons to work under pressure, helium sometimes is used as a diluent with oxygen to provide a breathing atmosphere. If air is used, nitrogen is dissolved in the tissues of the body under pressure. When pressure is relieved, the nitrogen forms bubbles resulting in the painful illness commonly called "the bends." As helium is relatively insoluble, this illness does not occur when it is used (see fig. 5).

Helium also is used in artificial breathing atmospheres whenever breathing by a patient is laborious. The lightness and rapid diffusion rate of helium reduce the effort required to breathe.

Helium is used as a diluent in some types of anaesthetics to reduce the hazards of inflammability and explosion (see fig. 6).

Tracer Gas

Helium is seldom found in appreciable amounts in oil and gas reservoirs. Recent developments in repressuring and recycling petroleum reservoirs have emphasized the desirability of knowing the manner in which injected gas spreads out in the reservoir formation. Because of its extremely low solubility, its high rate of diffusion, and the ease with which it can be detected, helium may be used as a tracer gas in investigating this problem. Experiments in the Elk Hills, California, field have proved conclusively that the migration of natural gas in underground reservoirs can be detected and measured when helium is used as a tracer.

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Figure 3. - Helium-shielded arc-welding operation (Northrop Aircraft photograph).

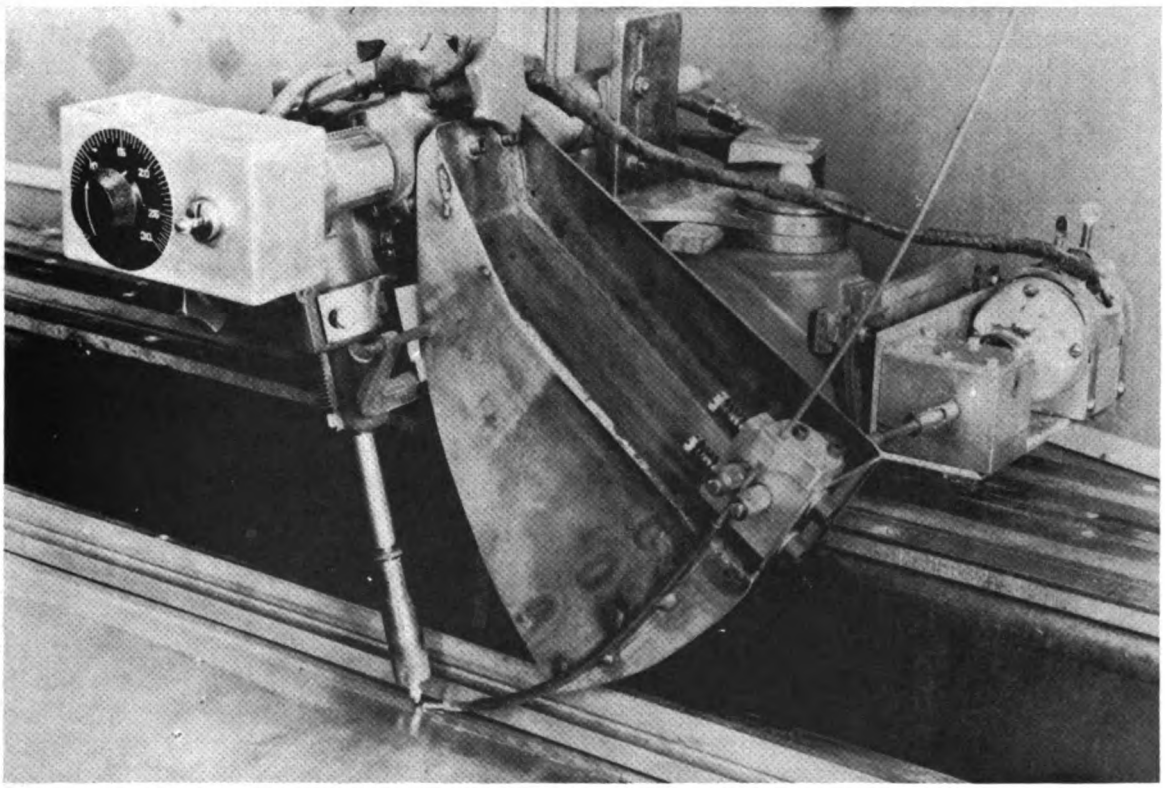

Figure 4. - Automatic Heliarc (helium-shielded arc) welder (Northrop Aircraft photograph).

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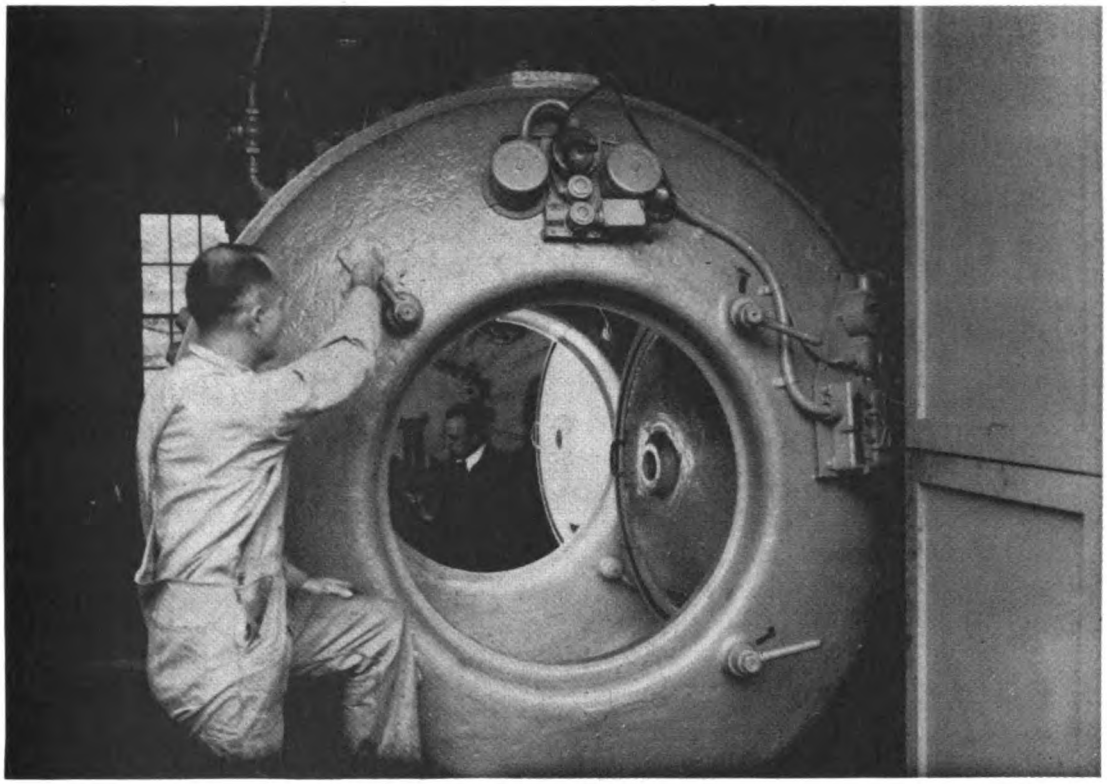

Figure 5. - Decompression chamber used by Bureau of Mines and U. S. Navy in employing helium-oxygen mixtures for deep-sea diving and caisson work.

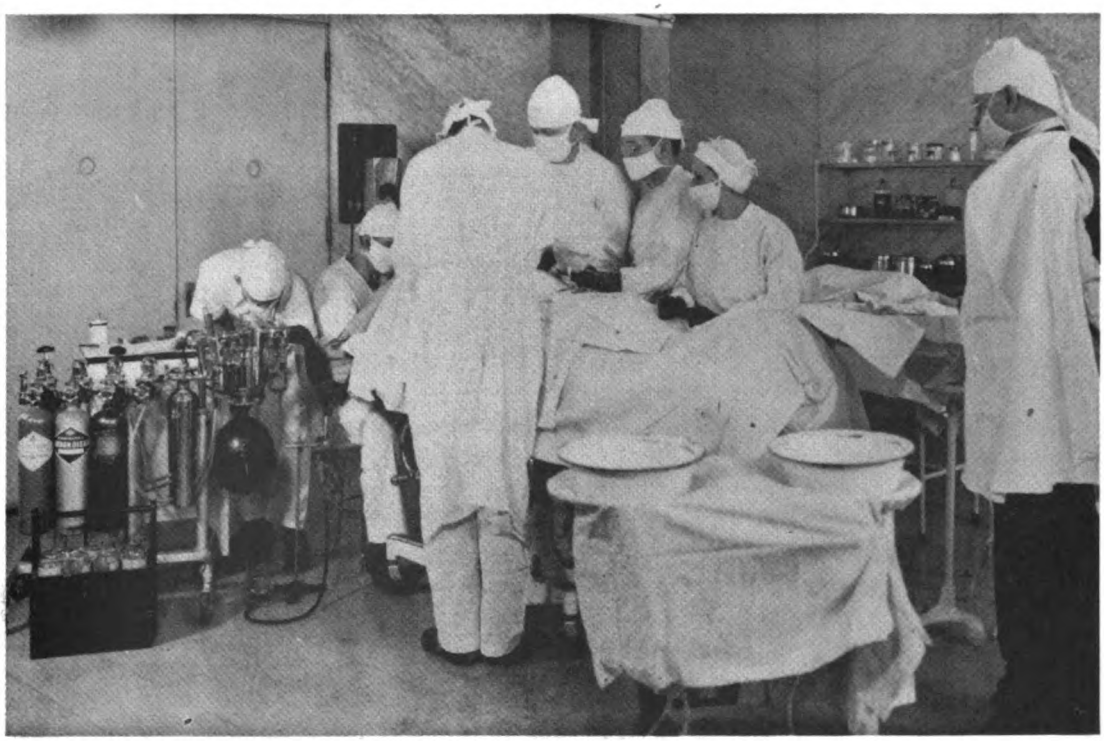

Figure 6. - Administration of anesthetic mixture in which helium is used to eliminate hazards of explosion.

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Low Temperatures

Helium may be used to obtain temperatures approaching absolute zero. Metals have remarkable properties at these temperatures; some of them, including mercury, lead, and tin, conduct an electrical current without any apparent diminished intensity. The metal becomes a "superconductor" of electricity. To date, these properties have been principally of scientific interest.

Chemical Raw Material

A discussion of atomic energy and relationships is beyond the scope of this paper, but the possibility of helium being used as a raw material in the synthesis of radioactive elements should not pass unmentioned. It has been known for some time that alpha particles emitted by radioactive substances are helium ions. In this age of synthesis many normal reactions have been reversed by scientists to obtain valuable products. It is impossible to foresee the direction that science will take after the war, but undoubtedly the atom will receive its share of attention and investigation.

TABLES SHOWING PROPERTIES OF HELIUM AND SOME OTHER GASES

In the following tables many technical terms and abbreviations are used.

Technical Terms

Absolute zero - temperature at which all molecular motion ceases theoretically.

Absolute pressure - pressure measured above that of a perfect vacuum.

Atmospheric pressure - pressure which normally exists at sea level; 14.7 pounds per square inch; 760 mm. mercury pressure.

Bunsen coefficient - solubility coefficient equal to the volume of gas measured at 0° C. and 760 mm. mercury pressure dissolved by 1 volume of solvent at the given temperature when the partial pressure of the gas is 760 mm.

British thermal unit (B. t. u.) - heat required to raise the temperature of 1 pound of water 1° F. at atmospheric pressure, varies with temperature, which must be stated.

Calorie - heat required to raise the temperature of 1 gram of water 1° C. at atmospheric pressure, varies with temperature, which must be stated.

Centigrade - thermometric system in which the freezing point of water is 0° and the boiling point 100° at atmospheric pressure.

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Centimeters of water, mercury, etc. - denotes pressure exerted by a vertical column of the substance.

Conductivity, thermal - time rate of transfer of heat by conduction through a substance.

Critical temperature - the temperature above which a gas cannot be liquefied by pressure alone.

Critical pressure - the pressure at which a substance may exist as a gas in equilibrium with the liquid at the critical temperature.

Critical density, volume - density or volume at critical conditions of temperature and pressure.

Density - mass per unit volume.

Dyne - unit of force which, when acting continuously on 1 gram of a substance and not opposed by another force will impart to the substance a uniform acceleration of 1 cm. per second.

Erg - work accomplished by a force of 1 dyne acting through a distance of 1 cm.

Fahrenheit - thermometric system in which 32° indicates the freezing point of water and 212° the boiling point at atmospheric pressure.

Heat capacity - heat required to increase the temperature of a substance by a given amount. See Specific heat.

Joule - 10^7 ergs (10,000,000 ergs).

Ostwald expression - solubility of a gas expressed as the ratio of distribution in a solution and in the vapor phase.

Poise - unit of viscosity. If the tangential force, per unit area, which one layer of a fluid exerts upon an adjacent one, is 1 dyne when the space variation of the tangential velocity from layer to layer is unity, the viscosity of the fluid is 1 poise.

Refraction, index of - the ratio of the sine of the angle of incidence from a vacuum upon a substance to the sine of the angle of refraction, each measured from the normal to the surface.

Solubility of gas - ratio of concentration of gas in the solution to the concentration of gas above the solution. See Bunsen coefficient, Ostwald expression.

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Specific gravity - ratio of density of a substance to a reference substance, usually water for liquids and solids, and air for gases.

Specific heat - heat required to raise the temperature of unit weight of a substance 1°.

Viscosity - resistance to flow and change of form.

Abbreviations and Symbols

Abs. - absolute

atm. - atmospheric pressure

C. - Centigrade

cal. - calorie

cm. - centimeter

$cm.^2$ - square centimeter

$cm.^3$ - cubic centimeter

cu. ft. - cubic foot

c - specific heat

Cp, C_v - specific heat
constant pressure
constant volume

D - density

deg. - degree C unless otherwise stated.

F. - Fahranheit

g - gram

l - liter

lb. - pound

liq. - liquid

m. - meter

ml. - milliliter

mm. - millimeter

n - refractive index

sec. - second

sp.gr. - specific gravity

T_c - critical temperature

P_c - critical pressure

V_c - critical volume

D_c - critical density

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TABLE 1. - Some General properties of certain gases

Taken from International Critical Tables except where otherwise indicated.

Property	Hydrogen	Helium	Nitrogen	Air	Argon
Molecular weight 1/	2.016	4.003	28.02	29 approx.	39.944
Gas Density (g./l. at 0° C. and 1 atm.)	.0899	.1785	1.2506	1.2930	1.7824
Density of saturated vapor at the normal boiling point (g./l.)	1.33	11.2 2/	4.61	-	5.89
Critical constants:					
Temperature (°C.)	-239.9	-267.9	-147.1	-	-122.4
Pressure (atm.) ...	12.8	2.26	33.5	-	48.0
Density (g./ml.) .	.031	.069	.311	-	.531
Specific heat (joules /gram-atom at 15° C. and 1 atm.)	14.5	20.9	14.56	-	20.2
Viscosity = A x 10^{-6} poises					
At 20° C. A = ...	88.7	197	-	284	221
At 23° C. A = ...	-	-	176	-	-
Liquid density (g./ml.)					
At -270.8° C.	-	.147	-	-	-
At boiling point	.0709	-	.808	.86	1.402
Boiling point (°C.)	-252.7	-268.9	-195.8	-194.2	-185.7
Latent heat of vaporization (kilojoule /gram-atom)	.450	.10	2.80	.18 per gram	6.3
Solid density (g./ml.)	.0808	-	1.026	-	1.65
Melting point (°C.)	-259.1	<-272.2	-209.8	-	-189.2

1/ Handbook of Chemistry and Physics.
2/ Estimated.

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TABLE 2. - Molecular constants

Taken from Handbook of Chemistry and Physics

Gas	Average velocity (cm./sec.) 0° C.	Average velocity (cm./sec.) 20° C.	Mean free path (cm. at 750 mm. Hg and 20° C.) 1/	Collision frequency, 20° C.	Molecular diameter, cm. 2/
Air	447 x 10^2	463 x 10^2	-	-	-
Argon	381	395	9.88 x 10^{-6}	4,000 x 10^6	2.94 x 10^{-8}
Helium	1,208	1,252	27.45	4,540	2.65
Hydrogen	1,696	1,755	17.44	10,060	2.34
Nitrogen	454	471	9.29	5,070	3.15
Oxygen	425	440	9.93	4,430	2.92

1/ Boltzmann.
2/ From van der Wall's equation.

TABLE 3. - Relative permeability of rubber

Taken from Bureau of Standards Scientific Paper 387

Gas	Relative permeability; hydrogen = 1	Gas	Relative permeability; hydrogen = 1
Nitrogen	0.16	Hydrogen	1.00
Air	.22	Carbon dioxide	2.9
Argon	.26	Ammonia	8.0
Oxygen	.45	Methyl chloride	18.5
Helium	.65	Ethyl chloride	200.0

TABLE 4. - Solubility of helium and some other gases in water

Taken from Handbook of Chemistry and Physics

Helium value is calculated from Henry's Law Constant, K

Alpha (α) = Bunsen coefficient of solubility is the volume of gas measured at 0° C. and 760 mm. Hg pressure dissolved by 1 volume of solvent at the given temperature when the partial pressure of the gas is 760 mm. Hg

Gas	Value of α At 0° C.	At 10° C.	At 20° C.	At 30° C.
Helium	0.0096	0.0090	0.0088	0.0086
Hydrogen	.02148	.01955	.01819	.01699
Atmospheric nitrogen	.02354	.01861	.01545	.01342
Oxygen	.04889	.03802	.03102	.02608
Carbon dioxide	1.713	1.194	.878	.665

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TABLE 5. - Solubility of helium in water (Wiebe and Gaddy, 1935)

Taken from Solubilities of Inorganic and Metal Organic Compounds

Partial pressure of helium (atm.)	Cubic centimeters (reduced to 0° C. and 760 mm. Hg) /gram H_2O			
	0° C.	25° C.	50° C.	75° C.
25	0.2322	0.2156	0.2225	0.2442
50	.4674	.4332	.4445	.4892
100	.9240	.8491	.8827	.9699
200	1.807	1.688	1.734	1.907
400	3.436	3.241	3.358	3.666
1000	7.421	7.263	7.536	8.251

TABLE 6. - Solubility of helium in some other liquids, Lannung 1930

Taken from Solubilities of Inorganic and Metal Organic Compounds

α = Same as in table 4

β = Ostwald expression, ratio of distribution of gas in solution and in the vapor phase

Temperature °C.	Methyl alcohol		Ethyl alcohol		Benzine		Cyclohexane	
	α	β	α	β	α	β	α	β
15	0.0298	0.0314	0.0268	0.0283	0.0165	0.0174	0.0220	0.0232
20	.0313	.0336	.0281	.0302	.0180	.0193	.0236	.0253
25	.0328	.0358	.0294	.0321	.0192	.0210	.0252	.0275
30	.0343	.0381	.0306	.0340	.0202	.0224	.0268	.0297
37	.0364	.0413	.0325	.0369	.0221	.0251	.0293	.0333

TABLE 7. - Viscosity

Taken from International Critical Tables

Gas	Temperature, °C.	Viscosity micropoises	Gas	Temperature, °C.	Viscosity, micropoises
Argon	23	221	Helium	23	196.2
Hydrogen	23	88.2	do.	0	186.
do.	0	84.2	do.	-70	156.4
do.	-257.7	5.7	do.	-102.6	139.2
Nitrogen	23.	176.5	do.	-191.6	87.1
Oxygen	23	203.9	do.	-237.4	27.0

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TABLE 8. - Index of Refraction, Gases

Taken from handbook of Chemistry and Physics

Values are relative to a vacuum and for a temperature of 0° C. and 760 mm. Hg pressure

Substance	Kind of light	Indices of refraction 1/	Observer
Air	D	1.0002926	Perreau
Argon	D	1.000281	Rayleigh
Carbon dioxide	D	1.000448	-
Helium	D	1.000036	Ramsey
Hydrogen	D	1.000132	Burton
Nitrogen	D	1.000296	-
Oxygen	D	1.000271	-

1/ Index of refraction is defined as the ratio of the sine of the angle of incidence from a vacuum upon a substance to the sine of the angle of refraction, each measured from the normal to the surface.

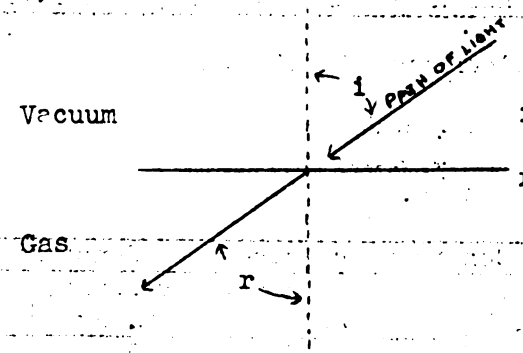

TABLE 9. - Specific heat at constant pressure

Taken from Gas Engineers Handbook except helium values, which were calculated from data in Thorpe's Dictionary of Applied Chemistry

Note: 1 B.t.u. /lb./°F. = 1 Cal. /g./°C.

Gas	Temperature °C.	Temperature °F.	C_p B.t.u. /lb./°F.	C_p B.t.u. / cu.ft. /°F.
Hydrogen	18	60	3.389	0.0180
Helium		-	1.26	.0133
Nitrogen		60	.248	.0184
Air		60	.240	.0184
Oxygen		60	.217	.0184

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TABLE 10. - Thermal conductivity

Taken from handbook of Chemistry and Physics

Conductivity is expressed in calories transmitted per second through 1 cm. of substance across an area of 1 sq. cm. when the temperature difference is 1° C.

Temperature of gas, °C.	Thermal conductivity	Observer
Air, 0°	0.0000568	Winklemann
Argon, 0°	.0000389	Schwarze
Helium, 0°	.000339	Do.
Hydrogen, 0°	.000327	Winklemann
Do. 100°	.000369	Graetz
Nitrogen, 7°-8°	.0000524	Winklemann

TABLE 11. - Coefficient of expansion of gases per degree fahrenheit

Taken from Balloon and Airship Gases

$$V = V_o (1 + \alpha_p t)$$
$$P = P_o (1 + \alpha_v t)$$
t in °F.

Gas	Temperature range, °F.	Constant pressure		Constant volume	
		Pressure, cm. Hg	Coefficient α_p	Pressure, cm. Hg	Coefficient, α_v
Air	-	75.2	0.00203667	76	0.00203944
Do.	32° - 212°	100.1	204133	100.1	204044
Do.	"	200.0	205016	257.	205167
Argon	-	51.7	203767	-	-
Helium	-	56.7	203611	-	-
Hydrogen	32° - 212°	100.	203478	100	203333
Nitrogen	32° - 212°	100.2	204133	-	-
Oxygen	-	75.9	204783	-	-

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TABLE 12. - P-V-T relations for helium gas

Taken from International Critical Tables

$\alpha_{o,t} = \frac{v - v_o}{t\, v_o}$ coefficient of expansion at constant pressure, P_o between 0° and t, °C.

$\beta_{o,t} = \frac{p - p_o}{t\, p_o}$ coefficient of expansion at constant volume v_o between 0° and t, °C.

	100α				
p, mm. Hg	0° to 50° C.	0° to 100° C.	0° to 200° C.	0° to 300° C.	0° to 400° C.
0	0.3660	0.3660	0.3660	0.3660	0.3660
1	.3658	.3658	.3658	.3658	.3658
10	.3635	.3634	.3633	.3632	.3633
20	.3609	.3608	.3606	.3605	.3605
30	.3584	.3582	.3579	.3578	.3578
40	.3558	.3556	.3552	.3551	.3551
50	.3532	.3529	.3526	.3524	.3525
60	.3506	.3503	.3501	.3498	.3499
70	.3481	.3477	.3475	.3473	.3474
80	.3455	.3450	.3450	.3447	.3448
1/v	100β				
0	0.3661	0.3661	0.3661	0.3660	0.3660
1	.3661	.3661	.3660	.3660	.3660
10	.3660	.3658	.3656	.3655	.3654
20	.3658	.3656	.3652	.3649	.3648
30	.3656	.3653	.3648	.3643	.3641
40	.3655	.3650	.3645	.3638	-
50	.3653	.3648	.3640	-	-
60	.3652	.3645	-	-	-

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TABLE 13. - Wave lengths of selected lines in emission spectrum of helium

Taken from International Critical Tables.

Unit of λ = 1 Å, 10^{-8} cm. The numbers in column G indicate the relative intensities of the lines in the Geissler-tube spectrum; 1 denotes the weakest line and 10 the strongest, but very strong lines are marked 15, 20, 25, or 30. I indicates that the line is emitted by the neutral atom; II the simple ionized atom.

	λ	G		λ	G		λ	G
I	40 540	-	I	4 387.93	3	I	2 945.10	6
I	20 581	20	I	4 143.76	2	I	2 829.06	4
I	10 830	5	I	20.81	3	I	2 763.80	2
I	829	1	I	4 026.19	5	I	33.24	7
I	7 281.35	3	I	3 964.73	4	I	2 511.22	5
I	7 065.19	5	I	3 388.65	10	I	2 385.39	5
I	6 678.15	6	I	19.60	4	I	06.12	2
I	5 875.62	10	I	3 613.64	3	I	2 252.81	2
I	4 921.93	4	I	3 447.59	2	II	1 640?	5
I	4 713.14	3	I	3 203.17	8	II	1 215?	-
I	4 471.48	6	I	3 187.74	8	I	585?	10

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